Study of EM Signals Propagation Through Marine Atmospheric Boundary Layer

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LONG-TERM GOALS

The long term goal of this project is to bring mechanistic understanding of the influence of the atmospheric conditions and sea state on the propagation pattern of EM signals over the ocean.

It is generally known that this propagation pattern is a combined result from the refractive structure of the marine atmospheric boundary layer and the scatterig properties of the rough ocean surface, although the quantitative role of each and the coupling between the two is incompletely understood. A special focus of this work is to study the wave-driven dynamics of the marine atmospheric boundary layer, pertinent to the layer's refractive structure and transmission properties. Until now little experimental input has been available on the subject.

OBJECTIVES

The propagation in ducting conditions, commonly occuring over the ocean, has been described by normal modes models (Hitney *et al.* (1985), Wait (1970), Bass and Fuks (1979)). Comparison with measurements has shown (Hitney (1999)) that such models tend to underestimate the EM signals propagation loss. High winds and waves present conditions where models and measurements disagree most. Therefore, reconsiling models and measurements, requires us to obtain experimental information for the refractive structure of the atmospheric layer over the ocean and the scattering properties of the wavy sea surface. One issue that must be addressed from the data is whether the refractive duct is sufficiently strong to confine the EM signals from escaping into space. However, the explanation for the discrepancy between models and measurements may be due to the fact that the models do not account for all the phenomena a signal is involved in when transmitted over the ocean. Other physical processes capable of degrading the energy of the EM signal and contracting its coherence radius are the scattering from the inhomogeneities of the atmospheric refractive index as well as scattering from the rough ocean surface (Ishimaru (1978), Rytov *et al.* (1987), Beckmann and Spizzichino (1963)). Of particular interest is the influence of the ocean surface waves, a distinct element of the marine environment, on the EM propagation. The waves influence on the propagation pattern by modifying the fluxes and profiles in the atmospheric boundary layer as well as by inducing refractivity fluctuations in the wind. The waves also determine the reflective properties of the sea surface (Barrick and Weber, (1977). The Miller-Brown model (Miller *et al.*, (1984)), describing the intensity of the coherent signal reflected from the sea surface, is based on assumptions verifiably inconsitent with our current knowledge about the statistics of sea surface and thus it requires reexamination.

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14. ABSTRACT
The long term goal of this project is to bring mechanistic understanding of the influence of the atmospheric conditions and sea state on the propagation pattern of EM signals over the ocean. It is generally known that this propagation pattern is a combined result from the refractive structure of the marine atmospheric boundary layer and the scatterig properties of the rough ocean surface, although the quantitative role of each and the coupling between the two is incompletely understood. A special focus of this work is to study the wave-driven dynamics of the marine atmospheric boundary layer, pertinent to the layer???s refractive structure and transmission properties. Until now little experimental input has been available on the subject.

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APPROACH

The variability of the atmospheric refractive index as well as scattering properties of the sea surface are being studied analyzing meteorological and waves measurements collected over the open ocean from *FLIP*. We are procesing the data for wind turbulence, temperature, humidity, ocean waves and currents, atmospheric pressure fluctuations, inertial navigation etc. We are employing analysis techniques proven to be productive for interpretation of open ocean data (Miller (1998), Hristov *et al.* (1998), Hristov *et al.* (2000)).

WORK COMPLETED

The field experiment has been completed, delivering quality measurements. Data were acquired continuously for two weeks. Wherever possible the signals were sampled at 50Hz. Overall the instruments performed well, except for the intermittent behavior of the sensors for fast humidity fluctuations. Although stormy conditions were of primary interest for the goals of RED, the wind speeds during the experiment remained moderate in the range between 5 and 10m/s and the standard deviation of the surface waves never exceeded 0.5m.

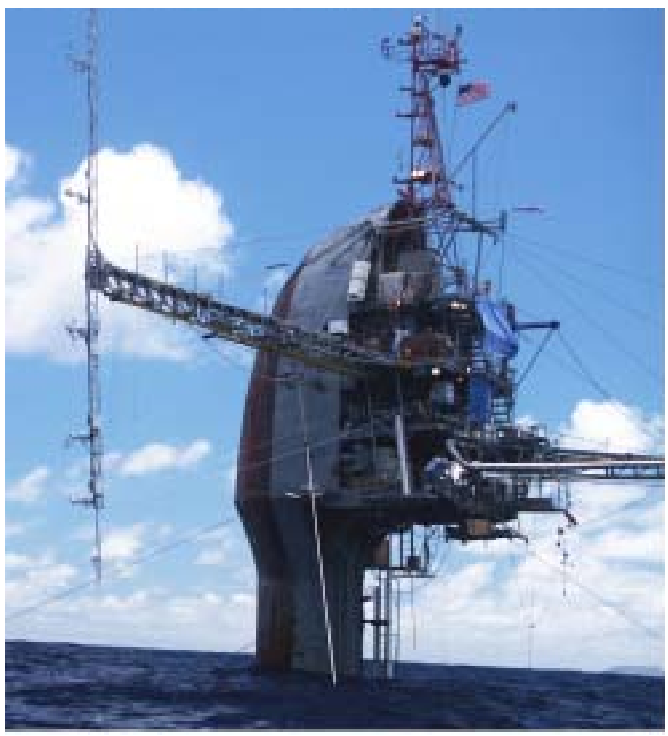

Figure 1. The experimental site at the Floating Instrument Platform (FLIP) during Rough Evaporation Duct (RED). Sonic anemometers/thermometers at 6 levels, a cup anemometer and a vane, pressure, humidity, temperature sensors, wave wire, and inertial navigation instruments were deployed from FLIP's port boom .

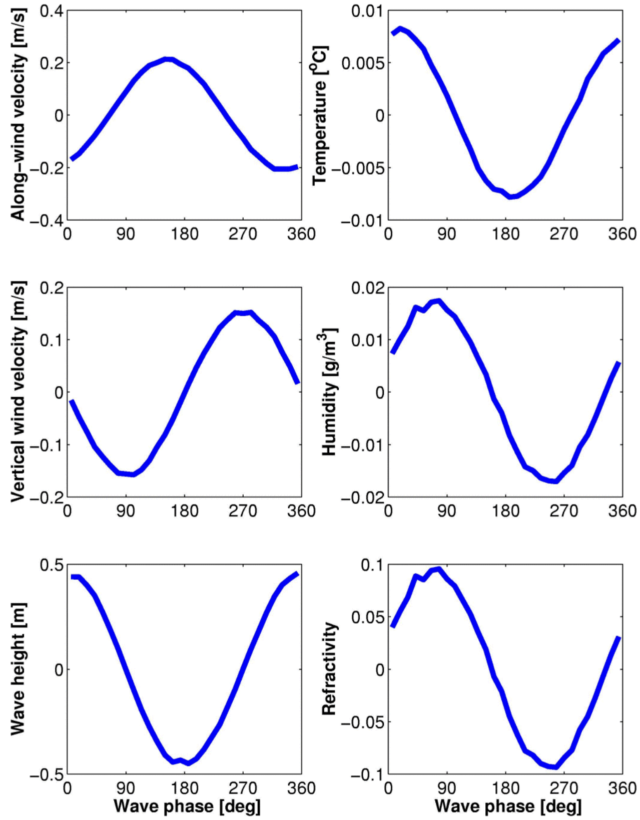

Figure 2. The conditional averages of along-wind and vertical velocity, wave elevation, air temperature, air humidity and air refractivity, with respect to the wave phase. The averages reveal how the surface waves deform the mean wind streamlines and thus cause wave-driven variation of the atmospheric refractivity.

RESULTS

We have proceeded with the interpretation of the collected data. The motion of the air in the atmospheric boundary layer is key to understanding the fluctuations of the refractive index over the ocean. Figure 2 summarizes the wave-driven dynamics of the atmospheric boundary layer, as detected by the instruments at the lowest mast level, 5.1m from the ocean surface. The ultrasonic anemometer provided the wind velocities. The temperature was recovered by superimposing the low frequency variability from the thermistor with the fast fluctuations from the ultrasonic thermometer, corrected for the presence of water vapor. Humidity signal came from the chilled mirror hygrometer. As for radio frequencies the humidity provides the largest contribution in the refractive variability (Bean and Dutton, (1968)), the atmospheric refractivity shows response to the wave forcing similar to the humidity's response. The conditional averages of along-wind $< u - \overline{u} \mid \Phi >$ and vertical $< w - \overline{w} \mid \Phi >$ velocities with respect to the wave phase (Hristov *et al.* (1998)), biased toward the dominant long-wave spectral components, are consistent with the predictions of the critical layer theory. Figure 2 shows how the oscillating ocean surface forces the profiles of along-wind velocity, temperature and humidity leading to fluctuations of the refractivity. In the case of negative vertical gradient of temperature (i.e. when the ocean is warmer than the air) an upward displacement of the surface and the wind's streamlines causes higher temperature at a fixed height over the wave crests. Same response to the wave forcing (i.e. higher humidity at fixed height over the wave crests) should be expected from the signal of humidity, and consequently, by the refractivity. The deviation from such behavior for the humidity and refractivity in Figure 2, likely results from the signal distortion inherent to the chilled mirror hygrometer. Figure 2 suggests that EM signals propagating over the ocean encounter a semi-periodic refractive structure, which along with the turbulence can degrade signal's energy (Tatarskii (1992)). The wave-induced fluctuations of the refractive index are unique to the oceanic environment. Their structure function does not follow the power 2/3 scaling law, valid for turbulent fluctuations, and thus their influence should be studied separately.

The spectrograms of the momentum and heat fluxes (Figure 3) provide physical insight into the boundary layer dynamics. The blue bands in the momentum flux spectrograms can be mostly attributed to the wave-induced momentum flux. As the wave-induced temperature fluctuations are virtually in phase with the surface elevation and therefore in quadrature with the wave-induced vertical velocity, no wave-induced heat flux is observed.

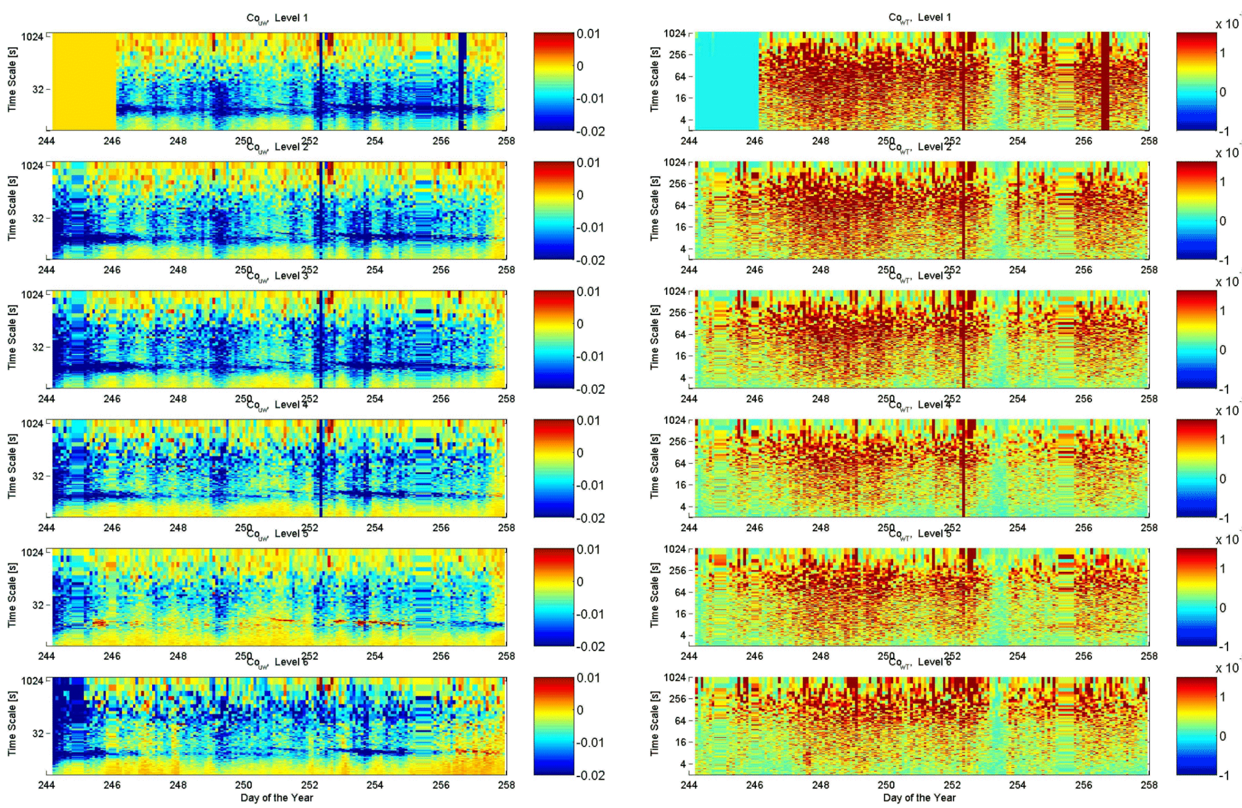

Figure 3. Spectrograms of the momentum (left) and heat (right) fluxes, obtained from measurements during the RED experiment.

IMPACT/APPLICATIONS

The data from the experiment will serve to reassess and upgrade models for EM signals propagation over the ocean. We expect that updated models will improve communications and radar applications conducted over the ocean.

TRANSITIONS

Air-sea interaction and surface waves studies will benefit from the results, measurement techniques and data interpretation methods obtained or developed in this research and the instruments built for this project. The data acquisition system implemented for this experiment has proven to be reliable, flexible, and scalable (i.e. allowing easy addition of new instruments). Analysis results as well as software for data management and interpretation are being provided to the RED team. The marine boundary layer dynamics, as inferred from these measurements, is useful in design and simulation studies of man-made objects flying low above the surface waves.

RELATED PROJECTS

The structure and dynamics of the marine boundary layer, whose impact on EM propagation is studied in RED, is also a focus of the CBLAST initiative (http://www.whoi.edu/science/AOPE/dept/CBLASTmain.html), currently supported by ONR.

SUMMARY

The Rough Evaporatrion Duct (RED) experiment was concluded, delivering quality measurements. The atmospheric conditions did not include storms, which were of primary interest for the goals of RED. The data analysis we now conduct, reveals the wave-driven dynamics of the atmospheric boundary layer, pertinent to its refractivity and transmision properties.

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PRESENTATIONS

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Hristov, T. S. and C. Friehe. Rough Evaporation Duct Workshop. University of California, San Diego. February 5-6, 2002.

Hristov, T. S. and C. Friehe. Poster presentation at the Spring meeting of the American Geophysical Union, Washington DC, May 28-31, 2002